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Human-System Integration for Future Command and Control: Identifying Research Issues and Approaches

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14. ABSTRACT *(Maximum 200 words)* The Army's transformation to Future Combat Systems (FCS) poses an unprecedented alliance of humans and machines, particularly for Command and Control (C^2). Creating a human-machine alliance that actually improves command and control is a severe challenge in human-system integration for FCS. First, this report selectively identifies four overarching research issues for command and control: Allocation, Autonomy, Authority, and Awareness. Second, two complementary research approaches, mid-scale and small-scale transformation environments, for investigating human-system integration issues are described. An example of a mid-scale transformation environment from the FCS C^2 program is provided with selected results from Experiment 1 on human-system integration. The value added by small-scale transformation environments, however, is needed to maintain a human-centric focus and provide two unique roles: a breeding ground for innovation *to* larger environments, and proving ground for issues *from* larger environments. An example of an emerging small-scale transformation environment directed at FCS concept exploration and training is provided. The core technical, operational and human performance assets currently available for this small-scale transformation environment are described. The report's intended audience includes any members of the user, researcher, and developer community who might benefit from, or provide benefit to, the Army's ongoing FCS research program.

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Research Report 1792

HUMAN-SYSTEM INTEGRATION FOR FUTURE COMMAND AND CONTROL: IDENTIFYING RESEARCH ISSUES AND APPROACHES

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FOREWORD

Concept exploration and development research for the Army's transformation to Future Combat Systems (FCS) is a key concern of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). The research issues and approaches identified here reflect ongoing work to address this concern by the Future Battlefield Conditions (FBC) Team of the Armored Forces Research Unit (AFRU). This report supports work package (211) FUTURETRAIN: Techniques and Tools for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Training of Future Brigade Combat Team Commanders and Staffs, and supports the Science & Technology Objective (STO) "*Methods and Measures of Commander-Centric Training*."

Creating a forceful alliance of humans and machines, particularly in the area of Command and Control (C^2), is a major human-system integration challenge for FCS. Unintended consequences of technology include an increase in the burden on humans because human-system integration is all too often an *unattended* issue. Moreover, the burden on humans from advances in military technology is caused not just by technology, but also by inflated expectations about technology.

This report identifies four overarching research issues for improving human-system integration in the area of command and control. Then two complementary research approaches, mid-scale and small-scale transformation environments, are described for investigating these and related human-system integration issues. The driving and integrative focus across all FCS transformation efforts should be the need to shape or transform technology to complement human performance.

The mid-scale transformation environment and findings reported here reflect ARI's ongoing involvement in FCS research, including FCS C^2 program efforts to explore new paradigms in command and control. The emerging small-scale transformation environment at ARI-Fort Knox underscores the unique and complementary roles of small-scale research with a human-centric focus. These roles convey research in smaller environment *to* and *from* the Army's larger FCS transformation environments.

Results of this effort were provided to the Program Manager (PM) FCS C^2 as part of ARI's ongoing efforts in support of the FCS C^2 research program. The intended audience for this report includes members of the user, researcher, and developer community who might benefit from, or provide benefit to, the Army's ongoing FCS research program.

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HUMAN-SYSTEM INTEGRATION FOR FUTURE COMMAND AND CONTROL: IDENTIFYING RESEARCH ISSUES AND APPROACHES

EXECUTIVE SUMMARY

Research Requirement:

The research requirement addressed in this report reflects the unprecedented alliance of humans and machines posed by Future Combat Systems (FCS). Achieving that alliance is a severe human-system integration challenge for FCS, particularly for Command and Control (C^2) at the small unit level. This report identifies research issues and approaches that reflect ongoing work by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) on FCS transformation.

Procedure:

A review of the literature selectively identified four overarching research issues for improving human-system integration in the area of command and control: Allocation, Autonomy, Authority, and Awareness. The literature review and ARI's experience led to several key conclusions. First, an unintended consequence of technology is that it often increases the burden on humans because human-system integration is all too often an *unattended* issue. Second, the burden on humans from advances in military technology is caused not just by technology, but also by inflated expectations about technology. Third, the Army learns by doing.

The research approaches identified here underscore the need for learn-by-doing environments, referred to as transformation environments. A mid-scale transformation environment is identified based on FCS C^2 program efforts to explore new paradigms for command and control. Description of this environment highlights how it embodies the key features of a transformation environment: empirical, scalable, iterative, collaborative, and human-centered. Selected results from FCS C^2's Experiment 1 are provided that stress human-system integration findings. Lessons learned are documented for refining the prototype FCS C^2 environment and improving human-system integration for the Unit Cell command group.

An emerging small-scale transformation environment at ARI-Fort Knox is also described. A status report describes this environment's core assets for creating an empirical venue that affords users, researchers and developers the ability to customize tasks and conditions in order to iteratively explore and transform concepts into viable, human-centric solutions. Core assets are summarized under technical, operational and human performance dimensions.

Findings:

The report concludes that a decisive value added by small-scale transformation efforts is the ability to maintain a human-centric focus, often lost in large-scale efforts. Moreover, the ability of technology to situate performance provides atypical power and potential to small-scale transformation environments. Two unique and complementary roles for small-scale

transformation environments are identified as: a breeding ground to cull and refine innovations for transfer *to* larger environments; and, a proving ground to assess and resolve key issues *from* larger environments.

Utilization of Findings:

Findings from this effort were provided to the Program Manager (PM) FCS C^2 as part of ARI's ongoing efforts in support of the FCS C^2 research program. Lessons learned for refining this environment and improving the command group's alliance with technology should help shape future FCS research and acquisition efforts. Research conducted in ARI's small-scale transformation environment will focus on innovations *to* and issues *from* the Army's larger FCS transformation efforts, including Fort Knox's role as proponent for FCS. Findings are also for members of the user, researcher, and developer community who might benefit from, or provide benefit to, the Army's ongoing FCS research program.

HUMAN-SYSTEM INTEGRATION FOR FUTURE COMMAND AND CONTROL: IDENTIFYING RESEARCH ISSUES AND APPROACHES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

HUMAN-SYSTEM INTEGRATION FOR FUTURE COMMAND AND CONTROL: IDENTIFYING RESEARCH ISSUES AND APPROACHES

The Army's transformation to Future Combat Systems (FCS) poses an unprecedented alliance of humans and machines. Examples of the alliance include humans working with intelligent agents or "bots" for information processing and decision aiding, and with robotic entities for moving, seeing and shooting. The potential impact of this alliance will pervade the force, but particularly the area of Command and Control (C^2) where expectations about new command and control paradigms are emerging. However, creating a human-machine alliance that actually improves, and does not impede, command and control is a human-system integration challenge for FCS.

This report is a small part of a large and expanding body of government and private sector work on human-system integration. An impetus for much of this work is the growing requirement for humans to interact with highly autonomous and complex systems that are all too often not designed to support such interaction (Olson & Sarter, 2001). The focus of this report is on identifying some key research issues and approaches directed at improving human-system integration, particularly for future command and control at the small unit level.

This report selectively identifies four overarching research issues for improving human-system integration in the area of command and control: Allocation, Autonomy, Authority, and Awareness. The report then describes two complementary research approaches, mid-scale and small-scale transformation environments, for investigating human-system integration issues.

This report's consideration of the research context for force transformation issues and approaches centers on several key themes. The profound changes essential to transformation require a comprehensive research approach that integrates and complements efforts across a range of small to large research environments. The research approaches identified here underscore the need for learn-by-doing environments, referred to as transformation environments. A working definition of a transformation environment is provided and its key characteristics are identified.

To complement FCS research efforts, the roles of small-scale transformation environments are identified as a breeding ground for innovation *to* larger environments, and a proving ground for issues *from* larger environments. To integrate FCS research efforts, the driving focus across transformation environments and efforts should be the need to shape or transform technology to complement human performance.

The research issues and approaches identified here reflect preliminary, ongoing work by the U.S. Army Research Institute's Future Battlefield Conditions team at Fort Knox. A primary purpose of this documentation is to disseminate and coordinate our team's efforts within the larger body of current and planned research on human-system integration. The report's intended audience includes any members of the user, researcher, and developer community who might benefit from, or provide benefit to, this evolving research program. Acknowledgement is made to the many members of that audience who's past efforts to improve the interaction of humans and machines guide future efforts.

RESEARCH ISSUES

A paradox of technology is that advances intended to ease our life and work often add complexity, difficulty, and frustration (Norman, 1988; 1997). In fact, Norman argues that humans and modern machines are becoming increasingly incompatible. Humans are analog devices designed to be compliant, flexible, and tolerant; many modern machines, particularly machines based on the exacting nature of digital technology, require us to be rigid, fixed, and intolerant. The dilemmas resulting from this paradox only escalate with our growing reliance on more complex and automated technology. The more critical our reliance on technology, the more pressing the need for research directed at ensuring technology's intended consequences and eliminating its unintended consequences.

This paradox is of particular concern to the design and development of FCS that entails an extraordinary amalgam of humans and machines, a truly hybrid future force. Currently, FCS is essentially a conceptual design featuring an interdependent system-of-systems (U.S. Army Training and Doctrine Command, 2001). This interdependence is reflected in the concept of a network-centric force composed of modular manned and progressively autonomous platforms with netted communication, sensor, and fire capabilities.

A pivotal example of the human-system integration challenge in FCS is the requirement that a relatively small command group can command and control an expansive mix of manned and autonomous systems. This command group requirement for the Unit Cell, the smallest combined arms echelon within the FCS structure, is the immediate focus of the research discussed here. This challenge is compounded by the command group's unprecedented reliance on technology, and the expectation that technology will enable new paradigms in command and control (Wass de Czege, in preparation). In sum, for FCS the integration of humans and automation is integral to conceptualizing and performing command and control.

The research issues confronting FCS human-system integration are numerous and daunting. Many of those issues are common to multiple-disciplines within and beyond the behavioral sciences. "In principle, it would be difficult to find a theory, paradigm, or body of empirical results in the cognitive and psychological sciences without the potential to illuminate some issue or problem in human-machine interaction" (Kirlik & Bisantz, 1999, p. 48). Notably, this report makes no attempt to review or summarize the vast and growing literature on human-system integration. For such reviews, interested readers are referred to Hancock (1999) and Salvendy (1997).

The goal of this section is to selectively identify a smaller, more workable set of overarching research issues for improving human-system integration in the area of future command and control. The issues identified were selected based on their perceived relevance to future command and control. Table 1 summarizes the four research issues identified that are briefly discussed below.

Table 1

Key Human-System Integration Issues Identified for Future Command and Control

Allocation	Interdependent tactics and technology constantly stressed the force to the limits of human capability.[1]	How to allocate human-machine functions?
Authority	Automation limits and overrides human operators.[2]	Who is in command?
Autonomy	Automated systems change their own behavior in response to changes in the situation.[2]	Who is in control?
Awareness	Commanders with digital systems had problems maintaining the big picture.[3]	How to maintain the big picture?

[1] Cordesman & Wagner (1996) [2] Sarter, & Woods (2000) [3] McGuiness, Foy and Forsey (2000)

Allocation

How to best allocate human-machine functions? The issue of how to allocate tasks and functions is a growing concern for force transformation. This discussion first highlights the issue of human-machine allocation in military operations in general, and then focuses directly on the area of command and control.

A fundamental lesson from modern warfare is that the insertion of technology tends to burden and stress the force, as documented by Cordesman & Wagner (1996). Their analysis of the Gulf War concluded that the war's influx of new technology stressed the force to the limits of human capability. Many of the technologies introduced were expected to ease operator burden, reduce fatigue, and simplify combat. Rather than unburdening military personnel, however, high-tech operations substantially raised the bar on human expertise, commitment, and endurance.

Notably, the burden on humans associated with advances in military technology is attributed less to technology per se, than to inflated expectations about technology. Cordesman and Wagner (1996) stress that the impact of heightened expectations on humans is pervasive; including technology enables more sorties, faster maneuver, extended fires, just-in-time logistics, and continuous operations. Moreover, "more with less" expectations about technology almost always include a "more with fewer personnel" premise.

The issue of how best to allocate human-machine functions and tasks is especially problematic in the area of command and control. Although automated systems are beginning to relieve commanders and staffs of many repetitive and computational tasks, the human tasks that remain are the most challenging and critical (Taylor, Charlton & Canham, 1996, p. 301). Many command and control tasks are too complicated and too important to assign to machines. For battle command, for example, advanced technologies should help commanders visualize the operation, describe it within their intent, and direct subordinates toward accomplishing the mission. However, the "science" of technology, severely lags the "art" of battle command.

Authority

Who is in command? The issue of command is a fundamental concern as technology becomes more autonomous. The high degree of automation occurring in some operational domains increasingly limits and overrides human decision makers, such as aircraft pilots (Sarter & Woods, 2000). Commercial aviation serves as a leading, natural laboratory for investigating human-system integration issues as it pioneered the introduction of autonomous systems in high-risk operational settings.

A telling example of system versus human authority in aviation is "envelope protection" (Sarter & Woods, 2000). Envelope protection is the power of air systems to automatically initiate recovery when any of a set of predefined situational conditions occurs, namely unsafe air configurations. When the aircraft approaches a defined unsafe condition, automation assumes direct control of the aircraft to avoid or recover from that condition, and this control includes the power to limit or override pilot input.

As the projected capabilities of FCS systems evolve, issues of *when* and *if* to keep the human in charge will become increasingly prominent. The system-of-systems architecture of FCS will raise system complexity and lower system observability to where informed command and even consent over autonomous systems is lost or imperiled. A revealing example is how the anticipated introduction of higher-order automation such as "intelligent" agents often adds complexity to, and reduces observability of, system interactions. Intelligent agents are software routines or programs that work as mediators between humans and lower level technology.

For FCS command and control, intelligent agents are expected to perform many roles such as aiding decision-making and "controlling" the execution of decisions as carried out by unmanned sensor and weapon platforms. Intelligent agents are expected to "understand" the directives and requests of humans, and then adequately translate these human inputs into software "commands" to lower-level automated systems. However, the complexity and uncertainty induced by mediating layers of technology can severely restrict the ability of humans to detect unexpected system difficulties and consequences, or even to provide informed consent (Olson & Sarter, 2001).

Autonomy

Who is in control? The issue of control is proving to be a problematic issue with more autonomous technology. The authority of command is often extended into control through the formulation of standing operating procedures (SOPs) that predefine and thereby limit the manner in which explicit and implicit commands must be performed. The autonomous capabilities of technology can be similarly curtailed by encoded procedures, software routines that restrict the potential autonomy of advanced technology.

Controlling strategies for managing automation such as management-by-exception and management-by-consent are receiving increased scrutiny (Olson & Sarter, 2001). In the case of management-by-exception, machines are allowed to initiate and perform actions independently. This strategy reduces human-machine interaction by the operator, but often demands more

intense human monitoring and a loss of awareness about the system and the situation. Conversely, a management-by-consent strategy requires the automated system to ask for and receive human permission before acting. A consent strategy tends to increase human awareness about the system and the situation, but also increases human interaction demands.

Operational answers about who is, or who should be, in control are neither clear nor fixed. As might be expected, humans in responsible roles initially opt for a management-by-consent strategy in order to maintain control (Olson & Sarter, 2001). However, these same humans often shift their preferred strategy on many tasks to management-by-exception after experiencing high workload, time pressure, and complex task requirements.

Preferences aside, objective performance data indicates that management-by-consent does not ensure effective control. Olson and Sarter (2001) suggest that despite its appeal, a management-by-consent strategy is severely compromised by technology advances that result in increasingly complicated and obscure automated systems. However, management-by-exception strategies entail severe risk, greater reliance on automation, and a decrease in human control and understanding of the system and situation.

Awareness

How to maintain human awareness of "the big picture?" The issue of human awareness is emerging as a pervasive, and to some degree unexpected, human-system integration issue the more technology advances. The ability of advanced information technology to increase the situational awareness of commanders and combatants by maintaining a common picture of the tactical situation is a basic expectation of FCS. Clearly, technology is steadily improving the ability to provide more accurate and timely depictions of tactical situations to commanders, combatants and supporters in mounted and dismounted settings. However, the ability to provide more data and information often limits and distorts human awareness.

A particular concern for command and control is the potential of information technology to limit commanders' overall awareness of the tactical situation. For example, McGuinness, Foy and Forsey (2000) compared the ability of Battlegroup commanders, equipped with digital C^2 systems versus voice radio and paper maps, to plan and execute a land reconnaissance operation. The only difference detected, across measures of workload and situational awareness, was that commanders with C^2 systems reported a significant decrease in their ability to comprehend the overall tactical situation.

A similar concern is emphasized by anecdotal assessments on the impact of live video from semi-autonomous Predator drones flying in Afghanistan (Ricks, 2002). A brigade commander reported he hardly watched the video because "the Predator can be mesmerizing -- like watching TV." A division fire support coordinator stated: "The danger is you get too focused on what you can see, and neglect what you can't see." Additional concerns about the impact of this unmanned aerial vehicle (UAV) included assessments that beaming the video to higher levels of command led to micromanagement of operations.

Advanced technology impacts human awareness at many levels, not just the ability to maintain an overall awareness of the situation, the bigger picture. In particular, the issue of maintaining system awareness with more autonomous systems has resulted in substantial research and findings that should be extended to FCS. Problematic issues in system awareness, such as mode awareness and automation surprises, reflect the difficulty humans experience in monitoring, anticipating, and redirecting more autonomous systems (e.g., Sarter, Billings, & Woods, 1997).

BACKGROUND ON RESEARCH APPROACHES

The Army's ongoing transformation to Future Combat Systems (FCS) entails profound change. The FCS concept requires a readily adaptive system-of-systems design to counter unforeseeable changes in threat capabilities and operations, and enable new paradigms for command and control. As underscored in this report, the FCS concept also requires an unprecedented alliance of humans and increasingly autonomous machines. Clearly, there is much to be learned to transform FCS concepts into reality. The Army learns by doing.

Transformation Environments

To learn by doing requires an empirical environment structured to support key learning objectives, including exploratory learning objectives. The research approaches identified in this section include the development of the required learn-by-doing environment, referred to as a transformation environment. A working definition of a transformation environment is provided to guide efforts in developing mid- and small-scale transformation environments for FCS research directed at human-system integration.

Transformation environments are empirical venues that afford users, researchers and developers the ability to customize tasks and conditions in order to iteratively explore and transform concepts into viable, human-centric solutions. Key features that distinguish a transformation environment are bulleted below.

- Empirical—ensure performance-based human-system interaction.
- Scalable—customize tasks and conditions to research issues and objectives.
- Iterative—focus on performance refinement.
- Collaborative—join users, researchers and developers.
- Human—shape technology to complement human performance.

More complete descriptions and examples of these features are provided in the following *Research Approaches* section that describes ongoing development of mid- and small-scale transformation environments directed at FCS command and control.

Notably, environments directed at transformation and concept exploration are not new, and are increasingly common in government and private sectors (Gold, 1999). Moreover, the set of environment features listed above are certainly not new and are common, at least in part, to many research and development efforts. In particular, the scale of a research environment is central to classic distinctions between field and laboratory research and their respective ability to

provide externally and internally valid results and findings. Similarly, the need for an iterative focus on concept and performance refinement is underscored in the "spiral development" process pioneered by the Army for force transformation (Gold, 1999).

However, the profound changes entailed in transformation require a unique mix of environmental features. The set of features proposed above addresses the sweeping purpose and scope of a transformation effort. In contrast, severe shortcomings often exist in the environments designed or cobbled together to foster transformation. For force transformation, multiple environments directed at different levels and issues are required, and their efforts must be closely coordinated.

Human considerations are often lost in large-scale efforts. Moreover, learn-by-doing transformation environments require a re-configurable performance-based venue that can customize tasks and conditions to learning objectives. The emphasis on an empirical environment underscores the need for objective measures of performance based on human-system interaction with prototype or actual FCS equipment. The ability to shape or scale the environment is crucial to iteratively refining concepts through lessons learned empirically. Notably, simulation environments are inherently scalable, and virtual simulation affords user-in-the-loop assessment and feedback. But larger scale environments, even when simulated, are more difficult and costly to reconfigure than mid- and small-scale environments.

In sum, developing the interdependent system-of-systems envisioned by FCS will require a wide range of complementary and closely integrated transformation environments. Building and sustaining an FCS infrastructure of transformation environments is essential to building and sustaining a rapidly adaptive force. Force dominance based on adaptability depends not so much on technology, but upon the ability of this infrastructure to integrate technology into the force (Carter & White, 2000). This ability equates to human-system integration, the requirement to shape technology to complement human performance.

A Scaled Research Approach Example

An example of a scaled-down research environment is described that stresses the importance of being able to customize tasks and conditions to meet research issues and objectives. The ability to scale down a research environment for a more human-centric focus is of particular concern to the research approaches described in this report. The theme of research scale is also used to relate the smaller scale research approaches described in this report to more comprehensive efforts, including large-scale transformation environments.

An example of why and how to scale down a research approach in support of command and control transformation is provided in the scaled world approach developed by Ehret, Gray and Kirschenbaum (2000). This example also reflects the exploratory mindset required for profound transformations: "We believe that the only aspects of the submarine officers' job that would not change in the next 25 years are the laws of physics regulating underwater sound propagation" (Ehret et al., 2000, p.13).

An answer as to why a scaled-down research approach is needed is provided in their description of a scaled world. A scaled world research approach serves as a middle ground between the situational complexity inherent in field research that resists definite conclusions, and the situational paucity of laboratory research that defies useful conclusions (Ehret et al., 2000). By design, it preserves key functional relationships based on questions of interest to evaluators or trainers, while paring away other functions that might confound answering those questions.

A scaled world approach was adopted to address the recurrent problem of tracking and analyzing how humans process information as they perform command and control tasks (Ehret et al., 2000). The goal was to derive a step-by-step record of how officers process information on their C^2 systems to localize an enemy submarine hiding in deep water. A scaled world approach was used to overcome problems encountered by the researchers in a high-fidelity environment. Problems in tracking officers' information processing as they used high-fidelity C^2 systems included: redundant information across displays; un-requested information encountered while navigating through intermediate displays, and copious information within displays that encouraged browsing.

To overcome such problems, a scaled-world version of the C^2 system was developed to more precisely track the information accessed by officers to localize enemy submarines. Scale-down modifications to the C^2 system included paring away some auxiliary functions, such as eliminating redundant information across displays and navigational changes that eliminated intermediate displays. At the same time, these modifications carefully ensured that the basic functions of the C^2 system were retained, including all information available for the localization task.

As a result of this scaled world approach, the researchers were able to identify and subsequently model officers' information processing activities (350-450 information accesses per scenario). The model was derived from logs of human-system interaction that were automatically segmented into officer-defined goals with 95 percent accuracy. Empirical comparisons between the officers' scaled world and real world performance were strongly supported, and the officer-expert model derived from this approach provides an excellent basis for training (Ehret et al., 2000).

Large-Scale Transformation Environments

Before turning to the research approaches central to this report—mid-scale and small-scale transformation environments—a very brief discussion of large-scale environments in support of transformation is provided. The intent of this discussion is to reinforce the need for complementary research approaches to address FCS human-system integration issues.

A cogent assessment of force transformation across the services by the Defense Science Board focused on the requirements for, and shortcomings of, large-scale efforts (Gold, 1999). The Board's report begins with the understanding that transformation is a process that seeks fundamental change in how an enterprise conducts its business. Their report notes that the transformation initiatives across the services seek common changes including: rapid

deployment, agility, small footprint, reachback, distributed operations, and exploitation of information in all dimensions of operation and planning.

The Board's requirements for large-scale transformation efforts stress the need for cross-service concept development and experimentation. To address this need, the Board urged decision makers to exercise the entire transformation process—from concept development through implementation—as soon as possible to address tough issues early on. To manage large-scale efforts, the Board recommended that objectives be limited to a manageable set. To facilitate that recommendation, they suggested transformation should not focus on all force elements, but on the synergies created by new and legacy forces. Notably, they also stressed that an urgent and steadfast commitment to transformation by a few, is crucial to overcoming the inertia and resistance of many.

However, many shortcomings in large-scale transformation efforts were cited in the Board's report. In particular, transformation efforts must "...avoid focusing on so-called 'Super-Bowl' events—expensive and unwieldy activities that inhibit learning" (Gold, 1999, p. 26). Instead, the report recommended that the transformation process employ a broad-based iterative approach using a variety of tools and venues that can lead to early discovery.

Many shortcomings inherent to large-scale environments, including transformation, training and testing efforts, are common to both field and simulation settings. An analysis of large-scale simulations by Simpson (1999) also concluded they usually focus on events versus process. Inevitably, the high costs in human and system resources required for large-scale efforts prohibit an *iterative* process of exploration or evaluation geared toward improvement.

For command and control transformation, limitations in large-scale environments are particularly severe. In part, the sheer size and complexity of modern C^2 systems complicates assessment and often limits its focus to technical versus human dimensions (Taylor et al., 1996). In addition, technology advances such as software upgrades to C^2 systems occur so frequently that iterative assessment is required. Taylor et al. (1996) also conclude that more comprehensive research approaches are needed for command and control that include an integrated mix of demonstrations, experiments, simulations, exercises, and formal tests.

In sum, large-scale transformation efforts are an essential component of research and development efforts directed at transformation, particularly in terms of external validity—value to the force. However, the focus of this report now returns to the need for complementary research approaches based on mid- and small-scale transformation environments.

RESEARCH APPROACHES

The research approaches identified here underscore the need for learn-by-doing transformation environments. A mid-scale transformation environment is identified based on FCS C^2 program efforts to explore new paradigms for command and control. Description of this environment highlights how it embodies the key features of a transformation environment: empirical, scalable, iterative, collaborative, and human-centered. Selected results from this effort's Experiment 1 are provided that stress human-system integration findings. Lessons

learned are documented for refining this environment and improving human-system integration for the Unit Cell command group.

An emerging small-scale transformation environment at ARI-Fort Knox is also described. A status report describes this environment's core assets for creating an empirical venue that affords users, researchers and developers the ability to customize tasks and conditions in order to iteratively explore and transform concepts into viable, human-centric solutions. Core assets are summarized under technical, operational and human performance dimensions.

Mid-Scale Transformation Environments

This section describes an emerging mid-scale transformation environment in support of FCS command and control. As noted, this research approach reflects preliminary and ongoing work by ARI in conjunction with other research and development teams. This brief description will highlight how this environment reflects many of the key features of a transformation environment previously considered. As research progresses beyond the Experiment 1 effort, summarized here, these environmental features will become more robust.

A case example of a mid-scale transformation environment for exploring command and control concepts at the small unit level is the FCS C^2 program. This program is a joint effort led by Defense Advanced Research Projects Agency (DARPA) and U.S. Army Communications–Electronics Command (CECOM) Research and Development Center (RDEC). During this program, October 2001 to March 2003, an iterative series of command-in-the-loop experiments will be conducted at CECOM. As a participating member in this effort, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) serves primarily on the FCS C^2 Human Performance Team and performs multiple research roles:

- Advises on experimental design, measurement, and training issues.
- Analyses command group behaviors through observation and post hoc analysis of recorded experimental trials.
- Conducts complementary in-house research directed at improving human-system integration in the area of command and control (see *Small-Scale Transformation Environments* section that follows).

The FCS C^2 Transformation Environment

The stated purpose of the FCS C^2 program is to test the hypothesis that digitization of current battlefield operating systems enables a *new* approach to command and control:

"If digitization of current battlefield operating systems can substantially enhance command and control by providing better, more accurate, and timely battlefield data to today's commander and staff for decision making; then a '<u>new</u>' approach to Battle Command and Control, implemented in the form of synthesized/analyzed information presented to the future Unit Cell Commander, will enable him to leverage of opportunities by focusing on fewer unknowns, clearly visualizing current and future end states, and dictating the tempo within a variety of environments, while being supported by a significantly reduced staff."

To test this hypothesis, the FCS C^2 program created and continues to refine a prototype transformation environment for empirical assessment of command group performance at the Unit Cell level. The concept of the FCS Unit Cell is evolving including its size and capability. Currently, the Unit Cell is the smallest combined arms echelon within the FCS structure. The Unit Cell concept proposes that a small command group—a commander and 1-5 additional personnel—can command and control a substantial number of manned and robotic elements performing a wide range of battlefield functions including reconnaissance, surveillance, targeting, and acquisition. Figure 1 depicts the manned and robotic elements of the Unit Cell employed in Experiment 1, including the C^2 Vehicle occupied by the cell's command group.

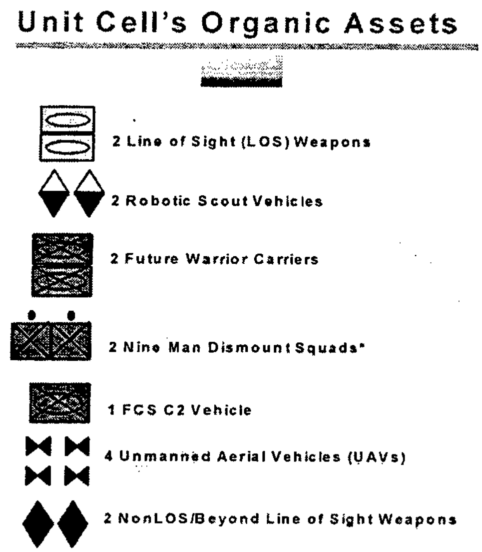

Figure 1. Organization of the Unit Cell during Experiment 1.

The resources and products of three interdependent teams—Operational, Technical, and Human Performance—were required to create this transformation environment for Experiment 1. The Technical Team developed the Commander's Support Environment (CSE), a hardware and software system, located in the command group's C^2 Vehicle. The CSE workstations for each member of the command group—Commander, Battle Space Manager, Information Manager, and Effects Manager—allowed them to command and control their Unit Cell elements.

The Technical Team also developed support technologies such as the Collaborative Server so the command group could share information via a common operational picture, and the Collective Intelligence module to ensure the Unit Cell's elements worked together in a network centric environment. Through the CSE's links to Distributed Interactive Simulation (DIS), the command group interacted with simulated elements of the Unit Cell, the threat force, and civilian entities.

The Operational Team collaborated on CSE design, developed the mission requirements and scenarios for Unit Cell operations, and provided players and supporters for Experiment 1. The command group players were four active duty U.S. Army Lieutenant Colonels deliberately selected to help explore and develop new paradigms for command and control. These players

were ably complemented by the expertise and vision provided by supporting personnel serving as Friendly and Enemy commanders and an Observer/Controller (O/C) team.

The Human Performance Team devised and implemented training and evaluation methods compatible with an incremental series of experiments designed to explore and document lessons learned for Army transformation and acquisition objectives. Team efforts focused on the human-machine interactions required for the Unit Cell concept, and stressed that a forceful alliance required shaping technology to complement human performance. This team collected and analyzed a variety of human performance data during Experiment 1, as discussed in a following section titled *Interim Findings: A Focus on Human-System Integration.*

Notably, formation and *sustainment* of an environment for concept exploration and development is required to transform FCS concepts into viable solutions. Experiment 1 assessed only the ability of the Unit Cell to move its elements in order to see the enemy and not be seen (i.e., See/Move). By Experiment 4, Unit Cell missions will include Improved See/Move/Strike/ Sustain and Transition requirements.

- Experiment 1—Dec. 2001—See/Move.
- Experiment 2—May 2002—Improved See/Move and Strike.
- Experiment 3—Sep. 2002—Improved See/Move/Strike and Sustain.
- Experiment 4—Feb. 2003—Improved See/Move/Strike/Sustain and Transition.

Similarly, the CSE technologies developed for Experiment 1 represented only about 20 percent of the full functionality envisioned for the Unit Cell's command group. As the experiments progress, new technologies will be added, and current technologies will be refined or abandoned based on lessons learned.

Experiment 1 Overview

The FCS C^2 Experiment 1 was conducted from 3-14 December, 2001. During the first week, program personnel trained the four command group players on operation of the CSE. During the second week, the actual experiment was conducted. A total of nine (9) experimental trials were run based on the Unit Cell's See/Move mission. After selected trials, the O/C team led After Action Reviews (AAR) that addressed operational, technical, and human performance issues.

The efforts of ARI in support of training and evaluation resulted in the use of deliberate practice methods, and the manipulation of trial complexity. Experiment 1 required that the players plan and execute essentially the same See/Move exercise across all experimental trials. The deliberate practice design included AAR performance feedback and afforded the players an opportunity to learn a demanding set of new command and control skills. The design also allowed experimenters to vary trial conditions as a function of METT-TC (mission, enemy, terrain, troops, time and civilians) among "Medium," "High" and "Too High" levels of trial complexity in order to gauge the performance limits of the Unit Cell.

Interim Findings: A Focus on Human-system Integration

Results from Experiment 1 are interim findings. These findings serve as benchmarks for subsequent experiments as well as formative development of the CSE and new paradigms of command and control. Results include objective and subjective measures of effectiveness and performance by the command group, the Unit Cell, and the CSE. For example, one key measure for the experiment's focus on See/Move was the percentage of threat elements located by the Unit Cell during a trial as a function of trial complexity (Medium, High, and Too High). Detailed results are documented in the Interim Report for Experiment 1, available from the Program Manager (PM) FCS C^2.

Interim findings on changes needed to improve human-system integration for the Unit Cell's command group were also documented (Sanders et. al., 2002). The data for these findings were collected from questionnaires, structured interviews, and fully recorded trials and AARs. These results include numerous recommendations from the command group players and AAR facilitators for improving CSE and command group performance.

Researchers from ARI observed Experiment 1 training and trials, and administered three data collection instruments: In-Place AAR, After Exercise Survey, and Exit Interview. In addition, ARI researchers performed a post hoc analysis of the verbal communications by the command group and higher headquarters cells during the experiment's nine runs in support of a Human Functions Assessment. Next, a small sample of results from each of these four research activities is presented. For interested readers, detailed documentation on the method, results and conclusions for this effort are available (Sanders et. al., 2002).

In-Place After Action Review (AAR).

Immediately after the completion of each trial run, a five to ten minute structured interview occurred called the In-Place AAR. This interview was administered by an ARI researcher with each of the player personnel still at their designated workstations in the mock-up C2 Vehicle, as shown in Figure 2. This setting allowed players to review and refer to their tactical displays as they provided a summary of their performance during the trial run. This setting also supported video and audio recording of all player comments and references to their tactical displays. This brief interview with each player asked for a short recapitulation of "what went right and what went wrong" relative to their duty position during the run. Results below are limited to a sample comment from each command group participant.

- Run 8, Battlespace Manager Comment: "This run represents the most effective integration of ground maneuver with aerial reconnaissance so far. The targets we initially missed, we were able to acquire eventually and to engage."
- Run 9, Information Manager Comment: "Right now the workload is OK at this station. As we get more detailed in doing the targeting and engagement, that may change in future runs."
- Run 5, Effects Manager Comment: "I got pretty hurried doing Inter-netted Unattended Ground Sensors (IUGS) fields and Loiter and Attack Munition (LAM) engagements and

Precision Attack Munition (PAM) engagements simultaneously, and then trying to (redirect my attention) up north to look at stuff."

Figure 2. In-Place AAR in the Commander's Support Environment.

- Run 8, Unit Cell Commander Comment: "In this run there was better integration and synchronization of assets, however, our prep reconnaissance-by-fire technique using LAMs and the smart munitions had minimal effect.

After Exercise Survey

This short survey was administered immediately after the command group participants exited the C2 Vehicle. The After Exercise Survey contained seven items that asked the command group players to assess key research issues (e.g., "What CSE features require more automation, and why?"). Sample player responses concerning CSE automation requirements included:

- Robotic vehicles should move autonomously to designated targets and locations
- There is no back up for the loss of aerial reconnaissance.
- Need easier and more flexible re-tasking.
- Need some sort of automated battle damage assessment (BDA).
- Improve planning collaboration among the command group's workstations.

The After Exercise Survey also asked players to rate their perceived workload and performance success (i.e., "How successful were you in accomplishing what you needed to do?"). Summary results on successful performance as a function of trial complexity are provided in Figure 3. Across the three subordinate members of the command group, there is a notable
decrease in estimates of success at the Too High level. In contrast, the Commander's ratings are relatively low and constant across trials, perhaps indicating higher performance standards.

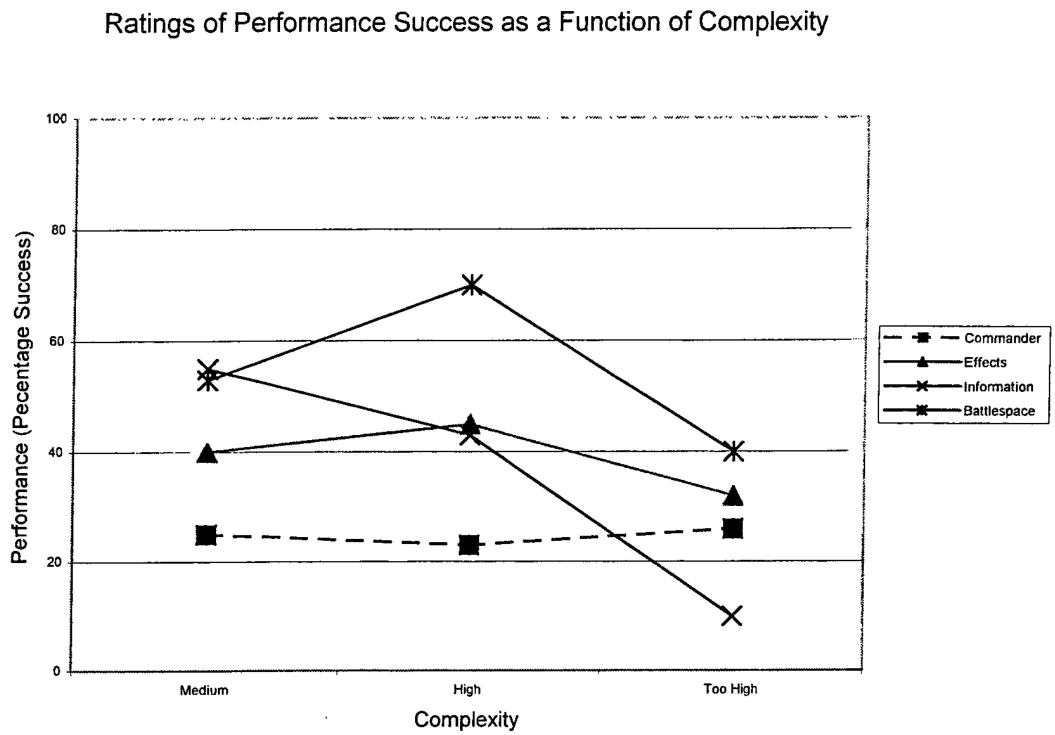

Figure 3. Ratings of performance success by trial complexity.

Exit Interview

On the final day, after all trials were completed, a structured Soldier-Machine-Functions interview was conducted with the Unit Cell Command and all three Battle Staff Managers. This interview investigated the human functions thought to be required for successful Unit Cell task performance. A small sample of comments provided by the players for several key functions follows:

- Maintain Battle Rhythm Comments: "There is a need for automated sensor-ganging; don't make us do this ourselves." "BDA needs to be automated, hands-off, with 'iconology' like a slash over a targeted icon to indicate it has been engaged."
- Use Planning Tools Comments: "Need a White Board. We probably don't need more Intel, what we need is a better way to share analysis." "We need a 3D tool for a detailed review of terrain to learn how to better use it; identify potential enemy keyhole positions."
- Maintain Situational Awareness Comments: "The present task allocation is good." "When we have a collaborative White-Board we can develop our own fires."

Human Functions Assessment

A post hoc analysis of the taped verbal communications among command group participants and higher echelons was conducted to assess human functions. For the nine Experiment 1 runs, communications were transcribed and separated into analytic chunks or blocks of

communication based on a Human Functions Rating Scale developed for that purpose, and the time duration for each block was recorded. Analysts used this scale to rate each block of communication with respect to Source, Function and Factor.

- Source: Within Cell, Cell to Black, Cell to White, and Black to White.
- Function: Plan, Move, See, and Shoot.
- Factor: Mission, Enemy, Terrain, Troops, Time, and Civilians (METT-TC).

For clarity, Source categorizations were: Within Cell corresponds to communications within the command group; Cell to Black, communications between command group and Black Cell headquarters; Cell to White, communications between command group and White Cell headquarters; and Black to White, communications between headquarter cells.

Figure 4 summarizes how communications were distributed on the average by Source and Factor, across the nine runs. Approximately 40% of Within Cell communications addressed friendly Troop assets, with most other command group communications split between Mission (27%) and Enemy (28%) factors. In contrast, headquarter communications between Black-White were predominantly about Enemy forces (77%), with the remainder devoted to the Mission Factor (23%).

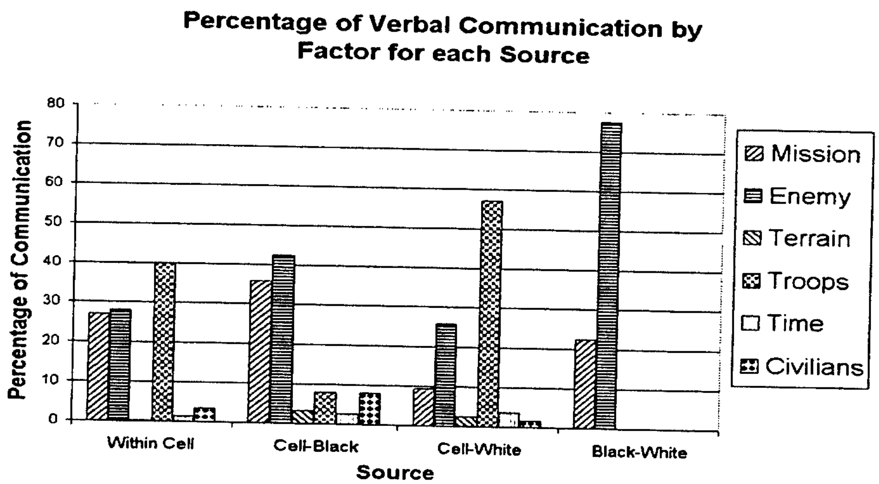

Figure 4. Percentage of verbal communication by Factor and Source.

Mid-Scale Environment Refinement and Research Issues

Overall, Experiment 1 was a decisive first step in the empirical assessment of Future Combat Systems (FCS) concepts of command and control by a Unit Cell over a large number of manned and robotic entities. The Experiment 1 efforts to build a transformation environment for FCS C^2 were in many ways successful. However, as expected, substantial work remains in refining and sustaining this environment for future research efforts. First, this section provides a brief overview of some general lessons learned for refining this environment. Second, more

specific lessons learned about human-system integration and the research issues of Allocation, Autonomy, Authority, and Awareness are considered.

Lessons Learned Overview

As part of its advisory role to the FCS C^2 Program, ARI provided the Program Manager a brief After Action Review (AAR) on Experiment 1. This review identified three Sustain and Improve topics to refine this transformation environment. Sustain topics, at least, partially addressed during Experiment 1 are bulleted below:

- Proactive and exploratory research compatible with FCS transformation objectives.
- Deliberate practice to promote proficiency for new command and control skills.
- Functional analysis focused on complementing human performance.

Each of these Sustain topics is discussed elsewhere in the current section *Mid-Scale Transformation Environments*, and that discussion is not repeated here. Improve topics not adequately addressed during Experiment 1 are discussed below.

Improve Training. New system training is always a challenge. The introduction of a new technology creates new tasks and roles for people at every level and introduces new errors, strategies, and expectations. The training challenge is compounded by a prototype technology, such as the CSE, as it includes the difficulty of developing a training program for an undocumented and continuously changing suite of complex functions. Shortcomings in training for Experiment 1 were notable, therefore, but to some degree unavoidable. Training improvements for subsequent experiments, however, must benefit from more complete documentation on system functionality at both individual and collective task levels. Training must also address the FCS C2 program's focus on more innovative and collaborative command and control. The operational concepts embodied by the CSE require new and unprecedented levels of collaboration within the Unit Cell, across echelons, and between humans and machines. Training for future efforts should include practical exercises that target each of these levels of collaboration, and that are based on clear training objectives. In summary, training improvements should:

- Document system functionality at individual and collective task levels.
- Develop practical exercises for collaboration within the Unit Cell, across echelons, and between humans and machines.

Improve the Link Between Thinking and Doing. Despite current rhetoric that the Unit Cell and Team levels are primarily doers not planners, the CSE should be modified to provide horizontal and vertical integration for planning activities. For example, during Experiment 1 the players had to repeatedly hand-jam intelligence updates from higher echelons into their CSE workstations just prior to execution. Another example, Unit Cell players and O/Cs strongly stressed the requirement for a Whiteboard, or John Madden Chalkboard, type capability. The ARI notes, however, that such boards usually support planning, rehearsal, and review modes, but not execution. Typically, after the commander depicts a course of action on a Whiteboard, players must manually re-input the same planning information into different formats or

applications required for execution. In sum, CSE improvements should provide direct links between thought and action, command and control, across manned and unmanned systems. This linkage should decrease command and control workload, error, and response times. In summary, thought and action linkages should:

- Ensure horizontal and vertical integration for planning activities.
- Develop a Whiteboard capability that transforms plans into actions.

Improve Enabling Technologies. A primary focus of the FCS C2 effort is to design and develop a prototype technology called the CSE that efficiently and effectively meets a Unit Cell's future command and control requirements. Although the CSE capabilities available to the players during Experiment 1 were impressive, extensive refinement of the CSE is required to provide and shape command and control enabling technologies. Low-level, more basic enablers include a wide range of human computer interface improvements. Selected examples include: icon aging, voice input, and user-friendly tasking of robotic entities (e.g., "Re-tasking problems cost me SA"—Battle Space Manager). Mid-level enablers are needed to ensure needed command and control information is proactively provided across planning and execution modes. Selected examples include: on-the-move depictions of critical "see" and "be seen" information, such as sensor footprints and platform inter-visibility; intuitive and effective alert mechanisms; and terrain analysis. Particularly, high-level enablers are needed to make current Unit Cell concepts viable. FCS, even at the Unit Cell level, is a net-dependent system of systems. Selected examples include: netted sensors for cross-cueing and verification, and for triangulation of threat locations; netted fires for sensor-shooter links and fire coordination; and netted communications for force multiplication within the Unit Cell and across echelons, and for failure management (i.e., avoid single-point failures). In summary, enabling technologies should:

- Provide low-level, more basic, human computer interface improvements.
- Provide mid-level proactive "push" of information in planning and execution.
- Provide high-level integration to include netted sensors, fires, and communications.

Lessons Learned on Research Issues

Observations made during Experiment 1, contributed to identification of the research issues of Allocation, Autonomy, Authority, and Awareness. Lessons learned concerning these research issues is summarized in Appendix A. The lessons documented in Appendix A focus primarily on improving research methods to address these issues in future FCS C2 experiments.

As noted in Appendix A, only the issue of how to allocate functions and tasks across the command group and supporting technology was clearly targeted before and during Experiment 1. Lessons documented in Appendix A reflect findings from Experiment 1, projections about future experiments and the previously reviewed literature on past efforts at improving the integration of humans and machines. The incremental development phases required to build a transformation environment, such as FCS C2, greatly influences when and how research issues can and may be addressed. For example, functions and tasks that burdened the command group in Experiment 1 may be shed, or shared by new technologies in future experiments.

In closing, the evolving FCS C^2 mid-scale transformation environment should become an important contributor in the exploration of command and control concepts to obtain viable solutions. Building on lessons learned, this environment should increasingly reflect many of the key features that characterize a transformation environment, particularly the collaborative and iterative efforts of interdependent Operational, Technical, and Human Performance teams. By design, the mid-scale nature of the FCS C^2 environment ably complements some shortcomings inherent to large-scale transformation environments. However, even a mid-scale research approach can't adequately address many key research requirements best approached in small-scale transformation environments.

Small-Scale Transformation Environments

This section focuses on the need for, and potential of, small-scale transformation environments, particularly in support of FCS command and control. The complementary role of small-scale transformation environments in relation to larger environments is first considered. Next, a description of a small-scale transformation environment currently under development by ARI at Fort Knox stresses how technology expands the potential of a small-scale environment, including integration with larger environments.

Value Added

This report stresses that a complementary range of transformation environments are needed to achieve the profound changes required for FCS force transformation. A similar conclusion was reached for transformation across the services, and for transformations directed at command and control (Gold, 1999; Taylor, et. al., 1996). A more unique conclusion made here is that the driving and integrative focus across transformation environments and efforts should be the need to shape or transform technology to complement human performance.

The decisive value added by small-scale transformation environments is the ability to maintain a human-centric focus. Failure to maintain that focus results in technology that adds complexity, difficulty, frustration, and failure per se. Notable examples of such failures in the area of command and control were previously considered under *Research Issues*. Human considerations are often lost in large-scale efforts, including modern warfare, where humans labor to support a maze of complex machines not designed to support them (Cordesman & Wagner, 1996).

What are the roles of small-scale transformation environment? How are those roles unique from the research conducted in larger environments? How do those roles complement, integrate with, the research conducted in larger environments? Two primary roles for smaller-scale transformation environments are bulleted and discussed below.

- Breeding Ground—to cull and refine innovations *for* larger environments.
- Proving Ground—to assess and resolve key issues *from* larger environments.

As preface to that discussion, complementary roles of small- to large- scale FCS transformation environments are depicted in Figure 5. The environments depicted in Figure 5

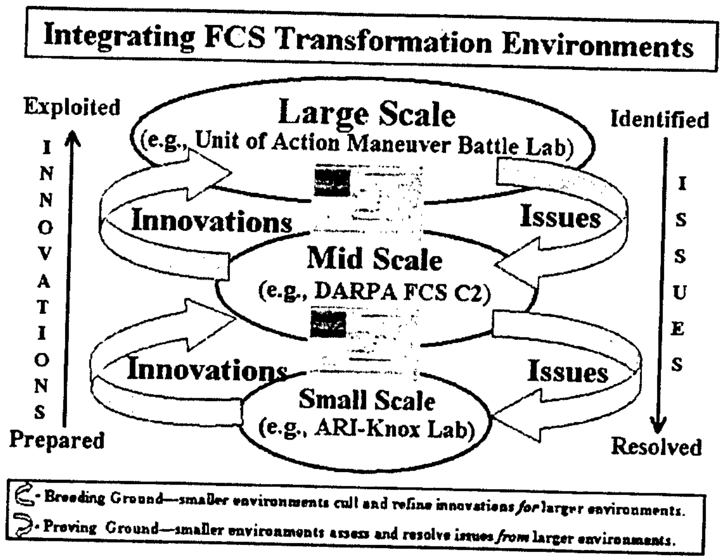

Figure 5. Integrating FCS Transformation Environments.

are only example environments most closely related to ARI's small-scale environment at Fort Knox, namely the FCS C^2 program discussed in the previous section and the Unit of Action Maneuver Battle Lab at Fort Knox discussed later in this section. There are multiple examples of FCS transformation at each level of effort that should be integrated. In particular, large-scale examples should include the Army's formal FCS development and acquisition efforts. Figure 5 also attempts to depict how command and control provides a common and shared framework for integrating transformation efforts, particularly in the form of advanced C^2 systems and displays.

Breeding Ground

A primary role of a small-scale transformation environment is to serve as a breeding ground of innovative concepts for larger environments. Smaller environments should serve as leading edge providers of potentially useful human-machine solutions to larger environments. As a provider of innovation, the small-scale environment must be able to cull or eliminate for transfer inadequate solutions, and prepare or refine innovations to a point adequate for transfer.

To perform the role of a breeding ground, a small-scale transformation environment should possess all of the characteristics previously identified: empirical, scalable, iterative, collaborative, and human-centered. An innovation often begins as a high-risk approximation of a *potentially* useful solution for many settings that is, in fact, not ready for any setting. Before innovations are inserted into costly and complex large-scale efforts, risk and readiness should be addressed. Smaller-scale efforts can empirically identify and iteratively refine innovations until adequate for transfer to larger environments.

Proving Ground

Another primary role of a small-scale transformation environment is to serve as a proving ground to help resolve key issues identified in larger environments. Small environments permit

more detailed and systematic assessment of the human-system integration issues that invariably surface during lager scale efforts, including operational tests on actual equipment. Testing and analysis may resolve the issue or refine a solution to a point ready for transfer back to the larger environment. Refinement may include human-centered requirements from users, or technical requirements to integrate the subject innovation with other technology in the larger environment.

Again, performing the role of a proving ground requires that a small-scale transformation environment have all of the characteristics of a transformation environment previously identified. Based on lessons learned, including the human-system integration literature reviewed, the issues that emerge in larger scale environments often result from a failure to address human-centric concerns early on. The ability of small-scale transformation environment to resolve human-centric design deficiencies is crucial to force transformation.

ARI's Emerging Small-Scale Transformation Environment

As part of ARI's research on FCS concept exploration and training our team is developing a multi-purpose research laboratory at Fort Knox. For concept exploration and development in support of command and control, this facility is being developed as a small-scale transformation environment. For future training, the vast changes envisioned—including embedded and distributed training, performance support systems, and intelligent tutors—also require an environment for exploration and transformation. Description of this emerging environment, therefore, focuses on its potential for addressing human-system integration and training issues.

Situated Performance

The theme of situated performance is introduced here to convey the power and potential of a small-scale transformation environment. This discussion of situated performance focuses on the validity and value of work performed in a smaller environment, and the relation of that work *to* and *from* larger transformation environments.

Performance and the readiness to perform depend on the situation. Situational emphasis is reinforced by the Army's tradition of performance-based training defined by tasks, *conditions*, and standards. This emphasis is reinforced by recent empirical findings that performance is rarely based on isolated cognition, but rather on an adaptive cycle of perception and action in response to the situation (Kirlik & Bisantz, 1999). Behavior out of context, including traditional small-scale laboratory research, is often not predictive of real world behavior.

With our growing reliance on technology, including computer-mediated work, the situation as experienced is increasingly a digital representation. Consider the integral role that digital representations on C^2 systems will play for FCS command and control. By design, C^2 systems situate performance, and are readily coupled to military simulations that generate realistic operational situations. The ability of a modern small-scale transformation environment to couple C^2 systems and simulations to more fully situate human performance provides atypical power and potential. This ability expands the situational scope of small-scale transformation

environments to literally global proportions, commensurate with the reach of simulation, C^2 systems, and FCS mission requirements.

For users, digital technology is the keystone of FCS transformation, particularly for command and control. This is underscored by the FCS concept of a network-centric force with netted communication, sensor, and fire capabilities. The common operational picture depicted on C^2 systems situates user perceptions and cognitions. The C^2 system also situates *performance* by serving as a microworld system in which inputs and outputs literally correspond to behaviors in the actual situation, including the behaviors of autonomous systems.

For researchers and developers, digital technology situates their performance by providing unprecedented *presence* in the world of users. This presence affords researchers and developers the ability to directly share, control, and track the situations that ground users' perceptions, cognitions and actions.

The ability to share directly and concurrently the situation and conditions affecting user performance helps researchers and developers relate performance to context, to the purpose of performance. The ability to modify and control performance situations—including repeatable and re-configurable conditions, and automatic and immediate feedback—enables systematic and iterative assessment of issues and refinement of innovations for larger environments. The ability to digitally track and collect performance data makes it possible for researchers and developers to *precisely* correlate task conditions, performance, and measures of performance.

Core Assets

Given the emerging status of ARI's small-scale transformation environment, this section describes this environment's core assets currently available and envisioned. These assets are summarized under technical, operational and human performance dimensions.

Technical. Overall, the technical infrastructure for this small-scale transformation environment provides an empirical venue that affords users, researchers and developers the ability to customize tasks and conditions in order to iteratively explore and transform concepts into viable, human-centric solutions. There are two core technical assets emphasized for this small-scale transformation environment:

- Situate users in realistic situations through simulation.
- Empower users to act on realistic situations through microworld C^2 systems.

For simulation, our team's emphasis is on virtual simulation to ensure user-in-the-loop performance and feedback. The principal form of virtual simulation for this environment will be Semi-Automated Forces (OneSAF), the Army's mainstream virtual simulation for concept exploration, training and acquisition. Currently, the most recent version called OneSAF Testbed Baseline (OTB) is operating in our facility. As OneSAF evolves it should continue to excel at situating user performance in realistic and futuristic operational situations.

The ability of any simulation to represent *future* operations and situations is a distinct and recurrent challenge. Ongoing work on FCS concept exploration by the Unit of Action Maneuver Battle Lab (UAMBL)[1] at Fort Knox continues to drive a cycle of OneSAF software upgrades that reflect the Army's transformation from concepts to FCS solutions. The OneSAF distribution agreement between UAMBL and others, including ARI, ensures continued access to OneSAF upgrades as new versions are developed. In addition, the distributed and open-ended nature of OneSAF supports linkages between virtual, constructive and live simulation environments.

Of special interest, OneSAF directly supports the requirement to integrate and complement FCS efforts across transformation environments. The re-configurable nature of OneSAF enables a range of environmental scales, including the relatively large-scale transformation efforts conducted by the UAMBL, and the mid-scale transformation efforts described for the FCS C^2 program. As a common medium across environments, OneSAF-based research will greatly facilitate the ability of our small-scale transformation environment to serve as a breeding and proving ground for larger environments.

Other forms of simulation will supplement our team's efforts to customize tasks and conditions to research issues and objectives. Currently, the Mission Planning and Rehearsal Suite (MPARS) is installed to help researchers plan, design, and develop simulation exercises as well as supporting materials such as maps and overlays. A completed MPARS file can be used to initialize a variety of simulation applications, including OneSAF. In addition, Microsoft Visual Basic™ provides a relatively low cost and highly exportable medium for customizing tasks and conditions, to include construction of a scaled-world (e.g., Ehret et al., 2000) and/or synthetic task environment (e.g., Schiflett & Elliott, 2000).

For digital C^2 systems, the core asset required is the ability to provide microworld representations of users' operational situations. Currently, the Force XXI Battle Command, Brigade and Below ($FBCB^2$) system is installed in our facility. The $FBCB^2$ system is fielded and serves as the primary C^2 system for digitally linking brigade and battalion echelons to soldier and platform levels. A futuristic C^2 prototype developed by the UAMBL for their work on concept exploration is also installed. This prototype serves as an "objective" C^2 system exemplifying many of the command and control capabilities anticipated for FCS. Other advantages of this C^2 prototype are its compatibility with OneSAF, its relatively unique status as a fully instrumented C^2 system, and its direct linkages to UAMBL efforts. Another C^2 system, currently under investigation by our team, is the previously described CSE prototype being developed by the FCS C^2 program to support a Unit Cell's command group.

Instrumentation to support data capture and analysis is another important technical asset for this environment. Initial assets required for post hoc analysis of the Experiment 1 results from the FCS C^2 program were minimal, the ability to playback video and audio recordings as well as the ability to analyze results with resident statistical packages. Assets now include the ability to record audio and video across multiple in-house research settings in analog and digital

[1] The UAMBL expands and reshapes what was formerly the Mounted Maneuver Battle Lab (MMBL).

™ Microsoft Visual Basic is a registered trademark of Microsoft Corporation.

format, and to relay any these recordings of user performance to an observer/controller room. Instrumentation will also provide the ability to capture all user-computer interactions precisely correlated with the situation in which they occur, including user-C^2 system interactions during simulated operations.

Operational. The user is essential to the value and validity of the research conducted in a transformation environment. Moreover, the overall contribution by operational personnel is much more than serving as research participants. Recall, members of the FCS C^2 Operational Team collaborated on C^2 system design, developed mission requirements and scenarios, and provided the expertise and vision of Friendly and Enemy commanders as well as an O/C team for exercise control and AARs. Products and guidance from this Operational Team will be leveraged in developing a small-scale transformation environment. In particular, this includes lessons learned and issues identified in this larger effort that might be better addressed in our team's smaller environment.

The ARI Field Unit at Fort Knox is positioned to ensure user involvement in nearly all aspects of the research planned for our small-scale transformation environment. Particularly, Fort Knox's Commanding General is the proponent for FCS and the Unit of Action, the echelon directly above the Unit Cell. For this proponent, the UAMBL will expand and reshape to serve as the FCS integration center, the hub of future force developmental work.

ARI has a long and sustained history of support to Fort Knox's Battle Lab that includes early work on a prototype C^2 system (e.g., Leibrecht, Meade, Schmidt, Doherty, & Lickteig, 1994) and on the Battle Lab's Battle Command Concept Experimentation Program (e.g., Throne, Holden, & Lickteig, 2000). Our Unit will continue work in this larger-scale transformation environment and this will include importing innovations into the UAMBL, and exporting key research issues from the Battle Lab into our small-scale environment for assessment and resolution.

In addition, ARI continues to work with the Armor School and the University of Mounted Warfare's efforts to train the officers, non commissioned officers, and enlisted soldiers of the future force. This includes ongoing work for the Armor Captains' Career Course, formerly known as the Armor Officers' Advanced Course (AOAC). Two aspects of this work are research on distance learning, particularly for the Reserve Component, and training methods to promote adaptive thinking. For example, the Armor Captains Career Course at Fort Knox has integrated a Think Like A Commander (TLAC) instructional module with cognitive drills to promote more adaptive battle command thinking (U.S. Army Research Institute, 2001).

Our Unit's association with the Armor School should provide us an excellent pool of research participants for user-in-the-loop assessment and feedback. The proximity of our Unit and the Armor School should support more informal arrangements for formative evaluations, and more formal troop support requirements for more rigorous assessments. Moreover, the current and future students of the Armor School embody the personal background and intuitive vision required to explore and exploit technology, and to ensure technology is shaped to complement human performance.

Human Performance. The core human performance asset for this transformation environment is ARI's FBC team at Fort Knox, the authors of this report. The members of this team are educated in the behavioral and cognitive sciences and experienced in the application of science to Army issues, including human-system integration. The FBC team will assist the Army's transformation efforts through this small-scale environment. Our Field Unit will continue its work in larger environments, including the FCS C^2 program and the UAMBL.

Additional assets within ARI include our Unit's collaboration with other Research Units, particularly in support of a Science & Technology Objective (STO) "*Methods and Measures of Commander-Centric Training*." Collaborative assets outside of ARI include our ongoing work with DARPA and CECOM on the FCS C^2 program, as well as numerous other government research and development organizations working on Army transformation.

Contractual efforts funded by ARI's Research Unit at Fort Knox provide additional human performance assets. Two contracts directly related to this small-scale transformation environment will address the need to scale-down research approaches by means of a synthetic task environment, and the need to develop prototype performance support systems. The research objectives in developing a synthetic task environment for selected C^2 functions include the ability to explore and develop future force concepts, and to train future leaders in the dynamics of emerging concepts.

Research objectives in developing a prototype performance support system include the ability to provide just-as-needed job support, in a manner readily adaptable to changes in human and machine performance requirements. The pervasive presence and potential of technology blurs the distinction between training *before* performing versus supporting *while* performing. Notably, performance support systems reflect the theme of situated performance.

Finally, two Small Business Innovation Research (SBIR) efforts are briefly noted that will contribute to the human performance, and technical, assets of our small-scale transformation environment. One SBIR is directed at developing a prototype Intelligent Tutoring System (ITS) for conceptual thinking, namely battle command reasoning. The objectives for this effort include: automated, on-line tutoring with deliberate practice opportunities, and a partial answer to the growing problem of limited expert human tutors. This challenging effort attempts to transfer the TLAC training approach from human to automated tutors, and provide the adaptive thinking skills increasingly required for command and control.

The second SBIR effort is directed at the design and development of intelligent technologies called "interface agents" to assist in the command and control of automated systems, such as robotic and intelligent entities. Research objectives for this effort include the development of tasking, monitoring and coordinating agents that can translate, and even anticipate, human inputs for lower-level automated systems. The expected benefit is to reduce human-machine interactions and training requirements, and support decision-making and communication across and within echelons.

In closing, as this small-scale research approach is still emerging, no research findings or lessons learned from this environment are provided. However, two examples are provided that

represent the research anticipated in this environment. First, our previously reported post hoc analysis of human-machine functions for the FCS C^2 program was the first research performed in this environment. This work, addressing the issue of Allocation and continuing throughout the FCS C^2 program, exemplifies this environment's role as a proving ground for larger scale transformation environments.

Second, our SBIR effort to develop interface agents to assist in the command and control of automated systems began only recently. Anticipated deliverables from this effort are software modules directly compatible with OneSAF and the Operator Control Unit used to control robotic entities in the UAMBL and other FCS transformation efforts. This work, addressing Autonomy and Authority issues and providing innovations ready for transfer to UAMBL, exemplifies this environment's role as breeding ground for larger scale transformation environments.

SUMMARY AND CONCLUSIONS

This report began by considering the human-system integration research requirement to meet FCS objectives, with a special focus on command and control at the small unit level. This research requirement is based on the unprecedented alliance of humans and machines posed by FCS. In support of that requirement, research issues and approaches were identified that reflect ongoing work by the U.S. Army Research Institute's Future Battlefield Conditions team at Fort Knox.

Four overarching research issues for improving human-system integration in command and control were selectively identified based on their perceived relevance to future command and control: Allocation, Autonomy, Authority, and Awareness. A review of human-system integration literature distilled two primary conclusions. First, an unintended consequence of technology is an increased burden on humans, as human-system integration is often an *unattended* issue. Second, the burden on humans from advances in military technology is caused not just by technology, but also by inflated expectations about technology.

As research context for the research approaches identified, key themes related to force transformation were established. First, the profound changes essential to transformation require a comprehensive research approach that integrates and complements efforts across a range of small to large research environments. Second, the driving and integrative focus across transformation efforts for FCS should be the need to shape or transform technology to complement human performance.

The notion of a transformation environment was introduced to overcome shortcomings in large and small transformation efforts cobbled together in a manner that does not attend to human performance issues. A working definition of a transformation environment was provided and its key characteristics identified: empirical, scalable, iterative, collaborative, and human-centered. The notion of a learn-by-doing environment was reinforced in subsequent descriptions of mid- and small-scale transformation environments.

A case example of an emerging mid-scale transformation environment was provided based on the FCS C^2 program. The stated purpose of the FCS C^2 program is to test the

hypothesis that digitization of current battlefield operating systems enables a *new* approach to command and control. Description of this environment highlighted how it reflects the key features of a transformation environment, particularly the resources and products of three interdependent Operational, Technical, and Human Performance Teams.

Selected results from the FCS C^2 program's Experiment 1 emphasized human-system integration findings, based on ARI's involvement in this research effort. These results focused on the FCS requirement that a small command group at the Unit Cell level can command and control an expansive mix of manned and autonomous systems. More general sustain and improve lessons learned for refining this environment were presented. And, more specific lessons learned about human-system integration and the issues of Allocation, Autonomy, Authority, and Awareness for the Unit Cell command group were examined.

A case example of an emerging small-scale transformation environment was provided that reflects the efforts of ARI in support of FCS concept exploration and future force training. The report concluded that a decisive value added by small-scale transformation environments is the ability to maintain a human-centric focus, often lost in large-scale efforts. Two unique and complementary roles for small-scale transformation environments were identified as: a breeding ground to cull and refine innovations for transfer *to* larger environments; and, a proving ground to assess and resolve key issues *from* larger environments.

The theme of situated performance underscored the fact that human performance is almost always based on an adaptive cycle of perception and action in response to the situation. Behavior out of context, a typical concern with small-scale research environments, often fails to predict real world behavior. However, technology now provides the ability to simulate realistic performance situations, and the ability to emulate and act on real world situations with digital C^2 systems. Small-scale transformation environments developed to exploit these technical capabilities possess atypical power and potential.

Finally, a status report described the core assets for ARI's emerging small-scale transformation environment. These assets will provide an empirical venue that affords users, researchers and developers the ability to customize tasks and conditions in order to iteratively explore and transform concepts into viable, human-centric solutions. Core assets were summarized under technical, operational and human performance dimensions.

Technical assets currently installed are designed to situate users in real world situations through simulation, such as OneSAF, and empower users to act on the same situations through microworld systems, including fielded and prototype C^2 systems. Technical assets also include a range of instrumentation to support data capture and analysis, including the ability to capture all user-computer interactions precisely correlated with the situation in which they occur.

Operational assets are essential to the value and validity of research in a transformation environment, and extend far beyond serving as research participants. Operational personnel will develop mission requirements and scenarios, collaborate on C^2 system design, and provide the expertise and vision required to explore and develop FCS concepts. Our unit's proximity to and

support of the proponent for FCS, the UAMBL, and the Armor School will provide invaluable access to operational assets.

Human performance assets for this transformation environment center on ARI personnel at Fort Knox educated in the cognitive and psychological sciences and experienced in the application of science to Army issues. Our ongoing work in larger environments, including the FCS C^2 program and the UAMBL, will relate and integrate the work performed in our small-scale environment *to* and *from* larger transformation environments.

In closing, a reminder that the primary purpose of this report is to disseminate and coordinate ARI's efforts within the body of research on human-system integration, and particularly FCS research. The intended audience includes members of the user, researcher, and developer community who might benefit from, or provide benefit to, the Army's ongoing FCS research program.

References

Carter, A. B., & White, J. P., (Eds.). (2000). Keeping the edge: Managing defense for the future. Cambridge, MA: Preventive Defense Project, 2000.

Cordesman, A. H. & Wagner, A. R. (1996). *The lessons of modern war, Volume IV: The Gulf war*. Boulder, CO: Westview Press.

Ehret, B. D., Gray, W. D., & Kirschenbaum, S. S. (2000). Contending with complexity: Developing and using a scaled world in applied cognitive research. *Human Factors*, *42*, (1), 8-23.

Endsley, M. R. & Garland, D. J., (Eds.). (2000). *Situation awareness analysis and measurement.* Mahwah, NJ: Lawrence Erlbaum Associates.

Gold, T. (1999). *Report of the Defense Science Board task force on DOD warfighting transformation.* Available from DTIC: ADA 369315.

Hancock, P., (Ed.), (1999). *Human Performance and Ergonomics*. San Diego, CA: Academic Press.

Kirlik, A. & Bisantz, A. (1999). Cognition in human-machine systems: Experiential and environmental aspects of adaptation. In P. Hancock, (Ed.), *Human Performance and Ergonomics* pp. 47-68. San Diego, CA: Academic Press.

Leibrecht, B. C., Meade, G. A., Schmidt, J. H., Doherty, W. J., & Lickteig, C. W. (1994). *Evaluation of the combat vehicle command and control system: Operational effectiveness of an armor battalion* (ARI Technical Report 998). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

McGuinness, B., Foy, L., & Forsey, T. (2000). B*attlespace digitization: SA issues for commanders.* Conference Proceedings from Human Performance, Situation Awareness & Automation: User-Centered Design for the New Millennium, *pp. 125-130.*

Norman, D. A. (1988). *The psychology of everyday things.* New York: Basic Books.

Norman, D. A. (1997). Being Analog. Online. Available at: http://www.jnd.org/dn.mss/being_analog .html

Olson, W. A. & Sarter, N. (2001). *Management by consent in human-machine systems: When and why it breaks down.* Human Factors, 43 (2), 255-266.

Ricks, T. E. (2002). *Beaming the battlefield home: Live video of Afghan fighting had questionable effect.* Washington Post, March 26, 2002, p. 1. Online. Available at: http://ebird.dtic.mil/Mar2002/e20020326beaming.htm

Salvendy G., (Ed.). (1997). *Handbook of human factors and ergonomics* 2nd ed., New York: John Wiley & Sons, Inc.

Sanders, W., Lickteig, C., Durlach, P., Rademacher, W., (MAJ), Holt, B., Rainey, S., Finley, D. & Lussier, J. (2002). *Future combat systems command and control (FCS C2) human functions assessment.* Available from the Program Manager (PM) FCS C^2.

Sarter, N. & Woods, D. (2000). Team play with a powerful and independent agent: A full-mission simulation study. *Human Factors*, 42 (3), 390-402.

Sarter, N., Billings, C., & Woods, D. (1997). Automation surprises. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* 2nd ed., pp. 1926-1943. New York: John Wiley and Sons, Inc.

Schiflett, S. G. & Elliott, L. R. (2000). Synthetic team training environments: Application to command and control aircrews. In H. F. O'Neil, Jr. & D. H. Andrews (Eds.). *Aircrew Training and Assessment*, pp. 311-335. Mahwah, NJ: Lawrence Earlbaum Associates.

Simpson, H. (1999). *Evaluating large-scale training simulations, Volume I; Reference manual.* Seaside, CA: Defense Manpower Data Center.

Taylor, B. H., Charlton, S. G. & Canham, L. S. (1996). Operability testing in command and control systems. In T. G. O'Brien & S. G. Charlton (Eds.), *Handbook of Human Factors Testing and Evaluation* (pp. 301-311). Mahwah, NJ: Lawrence Erlbaum Associates.

Throne, M. H., Holden, W. T. Jr., Lickteig, C. W. (2000). *Refinement of prototype staff evaluation methods for future forces: a focus on automated measures* (ARI Research Report 1764). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

U.S. Army Research Institute (2001). *Think Like A Commander* [Computer CD-ROM and Materials]. (Available from the U.S. Army Research Institute for the Behavioral and Social Sciences, 851 McClellan Ave, Fort Leavenworth, KS 66072).

U.S. Army Training and Doctrine Command. (2001). *The objective force maneuver unit of action concept: TRADOC Pamphlet 525-3-91 (Draft), Version 2.* Fort Monroe, VA: Author

Wass de Czege, H. (in preparation). *New Paradigm Tactics and Tactical Organizations: How to think about designing and fighting the Future Combat System based tactical organizations from Company to Corps.*

Appendix A

Lessons Learned on Research Issues

Observations made during Experiment 1, contributed to identification of the research issues of Allocation, Autonomy, Authority, and Awareness. However, only the issue of how to allocate functions and tasks across the command group and supporting technology was clearly targeted before and during Experiment 1. Lessons learned, therefore, are based on findings from Experiment 1, projections about future experiments, and the previously reviewed literature on past efforts at improving the integration of humans and machines.

In preface, the incremental development required to build a transformation environment, such as FCS C2, greatly influences when and how research issues can be addressed. Limited capabilities and requirements in Experiment 1 clearly limit findings and lessons learned. For example, functions and tasks that burdened the command group in Experiment 1 may be shed, or shared by new technologies in future experiments. These lessons learned focus primarily on the research methods required to address these issues in future FCS C2 experiments.

Allocation

Despite our team's limited success at developing methods for assessing human-machine allocation of FCS command and control functions and tasks, a basic conclusion is that substantial improvements in research methods are needed. For subjective assessments provided by the command group, functional categories on questionnaire and interview methods will be revised. For future experiments, these data collection instruments may ask respondents to assess functionality based on more basic and familiar categorizations, such as the Plan, See, Move, Strike and Sustain categories anticipated for a Unit Cell, and METT-TC. For objective assessment of command group performance, needed method refinements are bulleted below and then briefly discussed.

- Refine the categorization and coding of human-machine functionality, including verbal, nonverbal and cognitive behaviors.
- Refine the ability to visually review human-computer interactions in recorded runs and exercises.
- Develop the ability to automatically measure human-computer interactions, particularly command group and CSE interactions.
- Identify the training requirements and skill levels needed for FCS command and control, particularly at the Unit Cell level.

Refinements are needed to, and beyond, the Human Functions Rating Scale codes developed to analyze verbal communications from Experiment 1. An adequate analysis of FCS command and control must address both human and machine functions and how these are related. Moreover, the analysis of human functions must also include nonverbal behaviors, including perception and cognition. Methods are needed not only to capture and collate a wide range of human behaviors, but also to better understand behavioral components by assessing behavioral patterns across components, or relating behaviors. For example, humans routinely

analyze verbalizations by relating the communication to perceptual cues about what the speaker is looking at, pointing to, or doing at that time.

A first method refinement needed is to improve the codes used to assess human functions in Experiment 1. Method changes will focus on more precise categorizations of the Unit Cell players' behavior, including verbalizations, to improve inter-rater reliabilities. Breaking the verbalization blocks into smaller units before coding should help us reach inter-rater agreement at a minimum of 80%. A related step is to extend and refine the analysis codes developed for player verbalizations in a manner that maps or matches CSE functionality and other player behaviors. In sum, a common coding strategy across human and machine functions is needed to assess human-system integration.

A second method refinement needed is the ability to visually review the human-computer interactions of the command group on recorded videotape. During Experiment 1, the low quality of the analog video recordings did not allow for the identification of specific player actions with the CSE interface. As a result, the functional analysis was largely limited to the recorded verbalizations. In future experiments, digital recording formats should allow analysts to visually identify player interactions with the CSE interface as they perform operational tasks and functions.

A third method requirement is the ability to automatically measure player and CSE interactions to supplement the manual analysis of human and machine interactions. Manual analysis of audio and video recordings is laborious, time-consuming, and prone to error. In contrast, automated measures of human-computer interaction should increase the scope and precision of the functional analysis, and significantly decrease the analytic workload. A key recommendation for improving functional analysis in future experiments is to instrument the CSE in a manner that provides a log of all human-computer interactions.

A final method consideration is the need to identify the training requirements and skill levels for FCS command and control, particularly at the Unit Cell level. The FCS C2 experimentation program is exploring new paradigms in command and control. These paradigms, particularly expectations about multi-functional roles that encompass and extend traditional command and control functions, will entail new training and skill requirements. By identifying and describing command group behaviors for the Unit Cell, the analysis of human-machine functionality should directly support the need to identify training and skill requirements for FCS command and control.

Autonomy and Authority

Autonomy and Authority were not predefined research issues for Experiment 1, as noted. Limitations in automation during the first experiment, nevertheless, posed relatively few threats to the command group's efforts to command and control the Unit Cell. However, ongoing refinements to the CSE including a suite of alerts, advisories and decision aiding routines are expected to raise concerns about Autonomy and Authority in future experiments.

Findings from Experiment 1 do provide some interesting indicators about the relatively high degree of automation the command group is expecting. In particular, the command group expressed the need for more autonomous capabilities across maneuver and sensor platforms to reduce their workload, and to maintain the desired pace of operations or battle rhythm.

Concerning sensors, for example, the command group stressed the requirement that unmanned aerial vehicles (UAVs) have an auto-evade capability. After detecting jamming signals, auto-evade should allow UAVs to automatically alter their routes in order to avoid air defense artillery. They also stated that sensors should communicate with one another to collaboratively resolve target detection, recognition and identification requirements. The command group also felt overburdened by battle damage assessment requirements, and incapable of adequately performing such assessments given the Experiment 1 sensor capabilities. They recommended that micro UAVs should automatically key off Unit Cell target engagements, then fly out to the target and confirm kills, and report their assessment to the command group's CSE workstations.

Two method requirements, in particular, are stressed to assess the issues of Autonomy and Authority in future experiments. First, data collection methods should focus on the *observability* of the automation to the command group. The extent to which the command group can observe, query and understand automated functions in real time is critical to ensuring that the command group is actually in command and in control. This includes automation embedded in Unit Cell platforms, such as robotic scout vehicles and UAVs, and automation in their CSE workstations.

Second, the ability to automatically measure human-system interactions is needed to assess the command group's *use of* and *response to* automation. A key method requirement for assessing the issues of Autonomy and Authority, as noted, is to instrument the command group's interactions with CSE, particularly in response to alerts, advisories and decision aiding provided by the CSE.

Issues concerning management-by-exception and -consent were also not addressed during Experiment 1. However, given the relatively high workload experienced by the command group during Experiment 1 and their requests for more automation, a reasonable prediction is that they may opt for a management-by-exception strategy as more automation is introduced. However, optimal management strategies are an empirical question highly dependent on the overall suite of automated capabilities ultimately developed for this transformation environment.

Awareness

Awareness was, at least indirectly, addressed by Experiment 1's focus on the ability of the command group and Unit Cell to "See." Many objective measures of performance related to detecting and identifying Enemy forces, as well as limiting the Enemy's ability to detect and identify Friendly forces were collected. As noted, one such measure was the percentage of threat elements located by the Unit Cell during a trial. Results on these measures were documented, but restricted to the Interim Report for Experiment 1 available from the Program Manager (PM) FCS C^2.

Recall, this report's prior discussion of the Awareness issue focused particularly on how to maintain human awareness of "the big picture" as technology advances. The ability to maintain overall awareness amidst the deluge of new information provided by technology was not directly addressed during Experiment 1. However, observations during Experiment 1 indicated that the command group, and particularly the commander, lost the big picture at critical times.

The problem of maintaining overall awareness became a central point of discussion during several of the AARs that followed the Experiment 1 trial runs. The critical times identified in the AARs usually occurred during periods of intense activity, such as concentrated engagements. At such times, all four members of the command group seemed to simultaneously focus on the same small area of the battlefield where the engagements were occurring.

Data supporting a loss of awareness is often indirect or subjective. Notably, replays of each run during an AAR included the visible views of the battlefield as displayed on the CSE workstations for each member of the command group. One indirect indicator available from these replays was when the members of the command group had zoomed in their tactical displays to more directly view the engagement area in question. At such times, relatively large areas of the overall battlefield situation were not visible on any command group member's display. During the actual runs, there were also notable lags in the command group's detection of Enemy activity in battlefield areas not currently visible on any member's tactical display.

Other indicators the command group had temporarily lost the big picture included their reactions and comments during the run and subsequent AARs. Command group verbalizations during the run often indicated surprise when undetected Enemy activity was belatedly noticed by a member of the command group, or reported to them by headquarters. Such detections were usually followed by zooming displays out to view a larger area. Comments during the AAR included admissions by the command group that they had "lost the bubble" and their discussions about needing a standing operating procedure (SOP) to ensure at least one member of the command group always monitored the overall tactical area.

For future experiments, several methods are recommended for assessing Awareness, or loss of the big picture. Digital recording formats should allow analysts to visually identify human-machine interactions, including zooms and visible map areas, indicating that the overall battlefield was not being monitored. Visual analysis supplemented by verbal analysis of command group comments might better indicate surprise or lags in detecting key events.

Another needed method for assessing Awareness is the ability to automatically measure human and machine interactions, as noted earlier. For example, prior work by ARI on instrumented C^2 systems developed a variety of automated measures to assess human-machine performance (Throne, Holden & Lickteig, 2000). One of those measures, called Map Area, automatically compared the battlefield areas visible on the C^2 displays of a battalion level command and staff organization. A Map Area measure for the FCS C^2 program would help analysts identify patterns in display use that might indicate problems in maintaining Awareness.

More standard methods for assessing situational awareness (SA) may also be needed. Two methods in particular are recommended from the rather large toolkit of measures currently available (Endsley & Garland, 2000). First, a direct measurement approach called Situation Awareness Global Assessment Technique (SAGAT) is widely considered the best SA measure available. Second, a less intrusive method also recommended is the use of experimental probes to obtain "testable responses" of SA. Probes are a classic form of experimental manipulation that when carefully crafted can help relate SA to purposeful performance.